On the Hyperfine Structure Interval Rule in Indium

D. H. TOMBOULIAN AND R. F. BACHER
Cornell University, Ithaca, New York
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Interferometric measurements on λ7182 ($5s\ 6p\ ^3P_1 \rightarrow 5s\ 6s\ ^3S_1$) and λ7276 ($5s\ 6p\ ^3P_0 \rightarrow 5s\ 6s\ ^3S_1$) of In II indicate that the separations of the state $5s\ 6s\ ^3S_1$ follow the interval rule to within the experimental error (approximately 0.05 percent). Perturbations by neighboring states are negligible and there are no effects for this state due to the known electric quadrupole moment of the nucleus. The results indicate that the assumption of a nuclear magnetic moment is very successful in accounting for the observed relative separations.

THE interval rule in hyperfine structure follows directly from the interaction of a nuclear magnetic dipole in the field of the electrons. For several years it appeared that the hyperfine structure interval rule held in all cases as well as could be determined from the various measurements. This agreement was generally taken as meaning that the form of the interaction assumed to account for the hyperfine structure, was a good one. The accuracy and extent of the experimental data on which these observations were based, was not great enough, however. More recently, numerous deviations from the interval rule have been found in the hyperfine structure separations of various elements. These may be shown to be of two types. The first is due to perturbations of the individual hyperfine levels and observed when the hyperfine separations are comparable to the distance to an adjacent state. Numerous examples of such deviations are found in the work of Paschen and Campbell[1] on In II. The second, which is sometimes found where such perturbations are expected to be negligible, is attributed to an electric quadrupole moment of the atomic nucleus. Of course, all that can really be ascertained is that the interaction term which would be introduced by the presence of such an electric quadrupole moment accounts satisfactorily for the experimentally determined separations. Evidence has been found[2] which indicates that the same element mentioned above, In, shows deviations in the interval rule which are attributed to a nuclear quadrupole moment.

Not all states of the atom are expected to be affected by a nuclear electric quadrupole moment. For an electron with orbital angular momentum $l=0$, no effect is expected. This means that a configuration of s electrons is expected to have no quadrupole effect. Such a state is the $5s\ 6s\ ^3S_1$ of In II. In addition this state has no neighboring states nearer than the $^1S_0$ of the same configuration which is distant 3106 cm^{-1} and would therefore produce a negligible displacement of the central hyperfine level. Hence it is interesting to see how well the interval rule is followed in the absence of the effects which usually produce deviations.

To this end, interferometric measurements on the spectral lines of In II were extended to include two lines involving the $5s\ 6s\ ^3S_1$ state, as a supplement to the excellent grating measurements of Paschen and Campbell. A Fabry-Perot interferometer was used in conjunction with a Zeiss 3-prism spectrograph and the experimental arrangements were essentially the same as for the previous measurements[2] on In II. Fig. 1 shows an enlargement of the line λ7182 ($5s\ 6p\ ^3P_1 \rightarrow 5s\ 6s\ ^3S_1$) and the neighboring line λ7276 ($5s\ 6p\ ^3P_0 \rightarrow 5s\ 6s\ ^3S_1$) which lies under the He I line λ7281. All three components of In λ7276 are visible and there is no difficulty in distinguishing them from the helium fringes which are much broader.

A pattern of the line λ7182 as well as a level diagram is shown in Fig. 2. This line should show seven components but the central component was not observed due to its extremely small intensity. Paschen and Campbell observed this weak component only in the first order in their grating work. The $^3S_1$ separations are ob-

[1] Paschen and Campbell, Ann. d. Physik **31**, 29 (1938).
[2] Bacher and Tomboulian, Phys. Rev. **50**, 1096 (1936); **52**, 836 (1937); Schuler and Schmidt, Zeits. f. Physik **104**, 468 (1937).

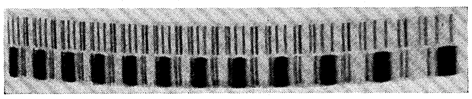

FIG. 1. Enlargement of photograph of λ7182 (above) and λ7276 taken with a 3 mm separator. The heavy fringes in the lower line are due to He λ7281.

tained directly from the differences, components (3–6) and components (2–5). The values of these separations are given in Table I as obtained from four plates taken with 3 mm separators and one with a 1 mm. The exact values of the plate separations as determined with neon standards are given in the first column of this table. For the 1 mm separator the pattern is not overlapped with that of adjacent orders but for the 3 mm separators it was. No components were superimposed, however. The *maximum* deviation from the mean is 0.0010 cm^{-1} (0.05 percent) for the larger separation and 0.0023 cm^{-1} (0.1 percent) for the smaller separation. From the same line Paschen and Campbell obtain 2.216 cm^{-1} and 1.797 cm^{-1} for the same separations. The separations of the $^3S_1$ state are checked by measurements on the line λ7276 ($5s\,6p\,^3P_0 \rightarrow 5s\,6s\,^3S_1$) which are also given in Table I. From this line Paschen and Campbell obtain 2.214 and 1.810 cm^{-1}. The present interferometric measurements show a greater consistency for the two lines as might be expected from the higher dispersion.

For a test of the interval rule the $^3S_1$ separations have been taken from the measurements of

TABLE I. *Separations of the* $5s\,6s\,^3S_1$ *state of* In II *as measured from λ7182 and λ7276.*

SEPARATOR MM	LINE A	INTERVAL 11/2−9/2 CM^{-1}	INTERVAL 9/2−7/2 CM^{-1}	WEIGHT
	From λ7182 ($5s\,6p\,^3P_1 \rightarrow 5s\,6s\,^3S_1$)			
3.12265	7182	2.2089	1.8104	1
3.12265	7182	2.2091	1.8069	1
3.12265	7182	2.2078	1.8076	1
3.00148	7182	2.2089	1.8082	1
1.05530	7182	2.2095	1.8073	1
	Average	*2.2088*	*1.8081*	
	From λ7276 ($5s\,6p\,^3P_0 \rightarrow 5s\,6s\,^3S_1$)			
3.00148	7276	2.2078	1.8091	3
3.00148	7276	2.2088	1.8109	1
	Average	*2.2081*	*1.8096*	

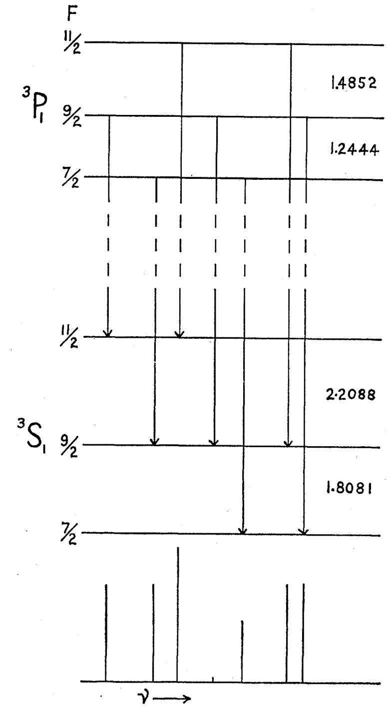

FIG. 2. Level scheme and observed structure for λ7182 ($5s\,6p\,^3P_1 \rightarrow 5s\,6s\,^3S_1$) of In II.

λ7182 since the effect of the background due to the neighboring helium line is rather hard to ascertain and might lead to some errors. The values of the separations give a ratio 1.2216 whereas if the interval rule held exactly they should be in the ratio of 11/9 or 1.2222. The difference between the ratios based on observed and calculated values is 0.05 percent which is probably within the experimental error. For the $5s\,6p\,^3P_1$ state the expected ratio on the basis of the interval rule is the same as above but the observed ratio is 1.1935. This difference is attributed to the perturbing effects of $^3P_2$ and $^3P_0$ of the same configuration.

The accuracy with which the ratio of the observed separations of $5s\,6s\,^3S_1$ agrees with the expected ratio indicates that the interval rule is followed very well in the absence of perturbations and quadrupole effects. Under these conditions the assumption of a nuclear magnetic dipole is remarkably successful in accounting for the observed relative separations.

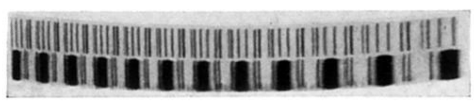

FIG. 1. Enlargement of photograph of λ7182 (above) and λ7276 taken with a 3 mm separator. The heavy fringes in the lower line are due to He λ7281.